Why ValueSTAC?

India is rapidly urbanising, putting tremendous pressure on the required infrastructure. Ensuring access to a reliable power supply is one of the most pressing challenges. Frequent power cuts and blackouts are rampant across India, leading large commercial and industrial (C&I) entities to rely heavily on diesel generators (DG). These generators not only contribute to local greenhouse gas emissions but also raise concerns about energy security and incur significant operational costs. To resolve these challenges, CEEW has developed an open-access techno-economic web tool called ValueSTAC to assess the feasibility of solar-plus-storage solutions, facilitate the replacement of DGs and promote greater adoption of solar-plus-storage solutions in India. Considering the large-scale deployment of distributed renewable energy technologies across the country, the tool will be crucial in supporting the greater adoption of solar-plus-storage systems. Battery storage will be a key enabler in ensuring grid stability, efficient energy management, reducing dependence on DG and fossil fuels, and accelerating the shift towards cleaner and more sustainable energy alternatives.

What is ValueSTAC?

ValueSTAC (Value of Solar-plus-storage: Techno-economic Analysis Calculator) is an open-source web tool designed to optimise battery energy storage systems (BESS) size by minimising the total cost of ownership (i.e., the sum of capital expenditure and operational expenditure). While the tool can serve a broad audience with varied interests, it is primarily targeted towards rooftop solar PV developers looking to start or expand their portfolio of solar-plus-storage solutions. Other users of the tool include commercial and industrial (C&I) consumers, policymakers, academicians, and researchers.

Objective:

The primary objective of this tool is to optimise battery size based on user consumption profile and outage profile and assess the techno-economic feasibility of a solar plus storage system over a diesel generator (DG) set. Diesel generator (DG) sets are widely used as an alternative power backup source during grid outages. They are also used in remote places as a primary source of electricity for consumers. However, in addition to being expensive, diesel usage also contributes to GHG emissions and local air pollution. Battery energy storage systems (BESS), coupled with rooftop solar, can offer not just a credible alternative to DG sets for backup but also multiple other value streams. These value streams include reduced diesel expenditure, increased self-consumption from rooftop solar systems, reduced demand charges, and time-of-day (ToD) tariff management.

Overview:

The tool comes with two different analysis types: the option to analyse their existing BESS system and the option to optimise battery size based on provided user inputs. In both cases, the inputs are divided into three sections First, the site selection and consumer category sections include demographics such as location and category. Second, the outage and load profile section consists of the load demand quantum and power outage patterns. Third, in the techno-economic specifications, system parameters such as the PV system size, battery size, value of lost load, analysis period, discount rate, etc, are specified for the solar generation profile. However, users can also input custom solar generation and demand.

Methodology:

The tool leverages NREL's PVWatts data to obtain hourly solar generation profiles across different cities and states and estimate emissions reductions. It applies the grid emission factors provided in the CEA baseline database. The tool incorporates a Time of Day (ToD) tariff structure alongside net metering and net billing mechanisms. For net metering, it has been considered that the electricity consumption in any time block, i.e. peak hours, off-peak hours, etc., shall first be compensated with the quantum of electricity injected into the same time block. Any excess generation over consumption in any time block in a billing cycle shall be carried forward to the corresponding time block in the subsequent month for adjustment purposes. The settlement period is considered as one year. It also offers advanced input options, allowing users to customise parameters such as electricity tariffs, feed-in tariffs, load demand, solar generation data, and dynamic monthly electricity consumption and outage profiles. These features enhance user flexibility, supporting a more precise evaluation.

Power dispatch algorithm

The consumer can choose either the default power dispatch algorithm or the energy arbitrage algorithm.

Default power dispatch algorithm: The following power dispatch algorithm is followed by default (Figure 1).

1. The solar PV system can generate electricity if connected to the grid (during non-outage hours), a battery, or a DG set.
2. The generation from the solar PV system is first used to meet the consumer's demand.
3. Any excess generation is used first to charge the battery and then, if the grid is available, to feed excess into the grid. In case of grid non-availability, excess generation after charging the battery is curtailed.
4. Any residual load after Step 2 is drawn from the electricity grid, if available. During an outage, the battery is discharged to meet the shortfall. If the battery cannot fully meet the residual load due to its power rating or charge depletion, the shortfall is categorised as unmet demand.

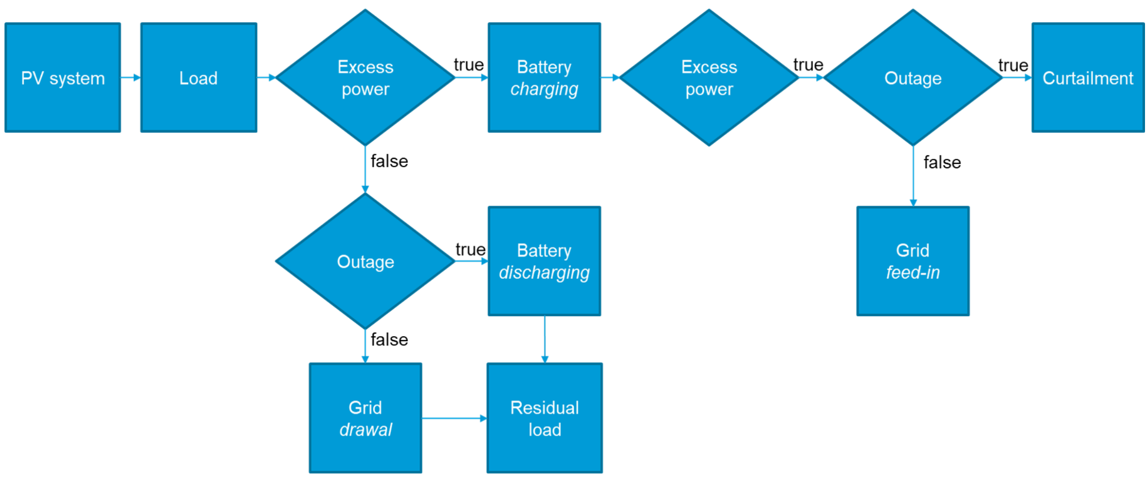

Figure 1 Default power dispatch algorithm

Energy arbitrage algorithm - Besides the default algorithm, the consumer is allowed to (a) charge the battery from the grid during non-outage hours and (b) discharge the battery to meet the load even when the grid is available. The consumer may choose to exercise options (a) and (b) separately during all time blocks or any time block. In practice, it is advisable to use Option (a) during off-peak hours and Option (b) during peak hours. Additionally, when exercising the option (b), the consumer may set a minimum battery SoC to ensure that the battery is not fully depleted before the outage starts.

The analysis covers four scenarios of electricity supply - (i) electricity grid + DG; (ii) electricity grid + solar PV; (iii) electricity grid + DG + solar PV; and (iv) electricity grid + solar PV + BESS.

Scenario I: Electricity grid + Diesel generator

If there is a power outage, the diesel generators will supply all the residual power; otherwise, all the power will be consumed from the electricity grid only. In this scenario, there will be no unmet demand.

Scenario II: Electricity grid + Solar PV:

The lesser value between solar generation and load demand for a specific block will determine the supply from solar to the load. In non-outage blocks, if solar generation exceeds the load demand for that block, the surplus energy will be fed back to the grid. Conversely, in outage blocks, the entire load demand will be classified as unmet demand.

Scenario III: Electricity grid + Diesel generator + Solar PV:

Scenarios II and III exhibit significant similarities; however, the primary difference is that during outage hours in scenario III, the required load will be supplied by DG rather than classified as an unmet load.

Scenario IV: Electricity grid + Solar PV + BESS:

Only this incorporates a battery storage system. The power flow simulation for this scenario is illustrated in Figure 1, which considers outage and non-outage, as well as the concepts of battery charging and discharging cycles.

Calculation of costs

The total cost of ownership (TCO) for the configuration can be broadly split into two categories - system-related costs and energy costs. System-related costs include the capital cost and the operational and maintenance (O&M) costs. Energy costs include the demand and energy components of the electricity bill, the cost of diesel, the cost of unmet demand.

1. **Capital cost:** This includes the capital cost of the solar PV system and the battery component. The battery's replacement cost is also incorporated into this at half the initial capex rate.
2. **Solar PV + battery O&M cost:** The O&M costs are assumed to occur at the beginning of each year. The initial annual O&M cost equals 1 per cent of the capex rate for the solar-plus-storage system (without replacement cost) and increases by 3 per cent annually thereafter.
3. **Electricity bill - demand component:** The demand component of the electricity bill is the product of the highest electricity drawn from the grid in the year and the demand charges.

4. **Electricity bill - energy component:** The energy component of the electricity bill is calculated separately for each ToD tariff block based on the metering regime as follows:
    a. **Hourly net billing** – In each hour, the consumer is billed at the electricity tariff corresponding to the ToD block if the consumer is drawing electricity from the grid and is compensated at the FiT rate if the consumer is feeding electricity to the grid. The bill/compensation for each hour is aggregated across the year to calculate the energy component of the annual electricity bill.
    b. **Monthly net metering** – In each month, the net electricity drawn from the grid across all hours of each ToD time block is calculated. If it is positive, it is billed at the corresponding retail electricity tariff rate; and if negative, the consumer is compensated at the corresponding FiT rate. The bill/compensation for each ToD block in each month is aggregated across the year to calculate the energy component of the annual electricity bill.
    c. **Annual net metering** – In each year, the net electricity drawn from the grid across all hours of each ToD time block is calculated. If it is positive, it is billed at the corresponding retail electricity tariff rate; and if negative, the consumer is compensated at the corresponding FiT rate. The bill/compensation for the three ToD blocks is aggregated across the year to calculate the energy component of the annual electricity bill.
5. **Cost of diesel:** If a DG set is used to provide backup, the residual demand after the solar-plus-storage system and the electricity grid are multiplied by the variable cost of generation from diesel (expressed in ₹/kWh) to obtain the cost of diesel.
6. **Cost of unmet demand:** If there is no DG set to provide backup, the residual demand is multiplied by the value of lost load to quantify the cost of unmet demand. In a given system configuration, only one of (5) and (6) would be present.

Costs (2) to (6) are weighted according to the discount factor, summed up across the years, and added to (1) to obtain the TCO for the configuration.

Optimisation of solar-plus-storage system

In order to optimise the size of the storage system, the power rating of the 4-hour battery is allowed to vary upto maximum allowable capacity (minimum of the maximum load demand and Solar PV system size). The battery capacity that results in the lowest TCO is considered to be the optimal battery capacity.

As mentioned earlier, the objective of the tool is to assess the techno-economic feasibility of solar plus storage solutions. Subsequently, all the techno-economic metrics are determined by comparing the scenario electricity grid + diesel generator with electricity grid + solar PV + BESS. However, the breakdown of total cost components and the Levelised Cost of Electricity (LCOE) can be compared across all four previously mentioned scenarios.

Basic Assumptions:

- Solar PV system cost - 0-1 kW INR 51,848/kW, 1-2 kW INR 48,316/kW ,2-3 kW INR 47,062/kW, 3-10 kW 45,909/kW, 10-100 kW INR 42,824/kW, >100 kW INR 40,192/kW. (Including all taxes).
- Battery cost -INR 10,500 /kWh (including all taxes).
- The battery replacement cost has been accounted for three times over a 25-year lifespan (after every 10 years), with the assumption that replacement batteries will cost half of the original price after the first 10 years and one-fourth after the next 10 years.
- Battery hours of storage are considered as 4 hours.
- The charging and discharging efficiency of the battery is considered to be 95%.
- The battery will not discharge below 20%.
- Discharging the battery when solar generation is less than load demand, and there is no outage during peak hours will ensure the battery does not discharge below 50%.
- The peak hours tariff rate is 20% higher than the normal hours tariff. (5:00 P.M.-11.00 P.M)
- The non-peak hours tariff rate is considered 20% lower than the normal hours tariff (11:00 P.M.-5:00 A.M.).
- The O&M cost is 1% of Capex cost which does not include the replacement of battery cost.
- The fixed charge has been considered as 60 /kWh/Month for Residential, 150 /kWh/Month for Commercial, and 300 /kWh/Month for Industrial consumer categories.
- Diesel Cost- INR 30/kWh
- Grid carbon emission factor-0.716 kg-CO_2/kWh
- Diesel carbon emission factor-0.76 kg-CO_2/kWh
- Solar degradation rate yearly -1%
- Battery degradation rate yearly -3%
- Annual load demand escalation rate -2%
- O&M cost escalation rate -3%
- Electricity tariff (Normal hours) escalation rate yearly -1%
- Annual demand charge escalation rate -1%
- Diesel cost escalation rate yearly -4%
- Annual value of lost load escalation rate -4%
- Feed-in-tariff escalation rate yearly- 0%
- Outage frequency as weekly two days - [3, 5, 10, 12, 15, 17, 22, 24] #Days
- Outage frequency as weekly three days - [1, 3, 5, 8, 10, 13, 15, 17, 19, 23, 25, 27] #Days
- Outage frequency as monthly three days- [8, 17, 24] #Days
- Outage frequency as monthly two days - [14, 27] #Days